

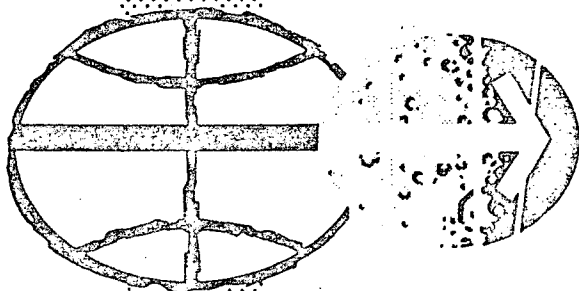


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA GENERAL WORKING PAPER

RECOVERY CONSIDERATIONS FOR POSSIBLE HIGH-INCLINATION
LONG-DURATION EARTH-ORBITAL MISSIONS

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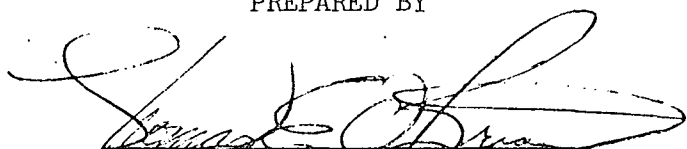
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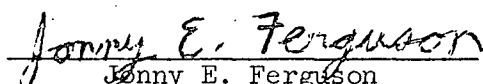
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RECOVERY CONSIDERATIONS FOR POSSIBLE HIGH-INCLINATION
LONG-DURATION EARTH-ORBITAL MISSIONS

PREPARED BY



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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RECOVERY CONSIDERATIONS FOR POSSIBLE HIGH-INCLINATION

LONG-DURATION EARTH-ORBITAL MISSIONS

By Thomas E. O'Briant and Jonny E. Ferguson

1.0 SUMMARY

This paper is based on a study of the effects on recovery planning of proposed long-duration high-inclination orbital missions using Apollo equipment. Problem areas are discussed and various solutions proposed. One of the major recovery problems encountered with missions having higher orbital inclinations than previous missions is the greater likelihood of severe weather conditions in the landing zones, especially if landing zones are optimized for orbital coverage considerations. Restricting the reentry window and increasing in-orbit wait times can partially eliminate the weather problem, but the possibility of emergency landings at higher latitudes still exists. It can be expected that the increased confidence level in spacecraft reliability that will exist by the time the high-inclination missions are flown will reduce the probabilities of an emergency landing in an unfavorable recovery location to a very low level (less than existing probabilities for current launch abort areas). However, the possibility remains that a recovery might have to be made under unfavorable weather conditions; therefore, environmental tests similar to those conducted for warm-weather landings should be conducted prior to the high-inclination mission operations.

High-inclination missions are likely to be of long duration, with missions of 2 months or more expected. With these long-duration missions, either an increase in the Department of Defense support requirements will be necessary or an increase in the in-orbit wait of the spacecraft must be permitted. The present recovery support concept used for earth-orbital missions, requiring four recovery zones, is impractical for long-duration missions because of the large number of ships at sea that would be required to maintain current in-orbit wait times for early mission termination. With increased spacecraft confidence, two recovery zones centered at ports accessible to U.S. ships could be used. Minor increases in in-orbit wait time would result, but these would probably be acceptable. Thus, ship and manpower requirements could be held to a reasonable level.

The conclusions drawn are as follows:

1. Prior to high-inclination long-duration orbital mission operations, sufficient confidence must be gained in the Apollo equipment to allow a 12-hour in-orbit wait time.
2. Planned landing areas should not be outside the 40° N to 40° S latitude band.
3. Recovery operations environments up to 50° latitude should be considered in the design of spacecraft postlanding systems, recovery equipment, and procedures prior to conducting high-inclination missions.

2.0 INTRODUCTION

Manned earth-orbital missions are being planned with earth observations as one of the prime purposes. These observations will be made by spending much flight time over landmasses. It is presently expected that such missions will have durations in excess of 2 months and orbital inclinations of up to 50° . Such increases in mission duration and orbital inclination over previous flights present increased problems associated with recovery operations. These difficulties center on the greater frequency of severe weather at higher latitudes where landings might have to be made and the selection of acceptable trade-offs between considerations such as increases in recovery support and spacecraft in-orbit wait time. The purpose of this paper is to give the reader an understanding of some of the major adjustments in recovery planning and operations which must be made to prepare for these long-duration high-inclination missions and to recommend some approaches toward the resolution of the related problems.

3.0 RECOVERY SUPPORT PHILOSOPHY

In general, recovery support for earth-orbital missions can be grouped into three broad categories: (1) support required for possible launch aborts, (2) support required for possible aborts from orbit, and (3) support required for the end-of-mission landing area.

The recovery support areas for aborts during the launch phase of a given mission encompass the launch ground track. Some examples of ground tracks to achieve orbital inclinations of $32\text{-}1/2^{\circ}$, 40° , 45° , and 50° are shown in figure 1. Ships and aircraft are positioned at optimum points along the launch ground track to be near the high-probability landing areas.

During orbital flight, a spacecraft landing is possible anywhere along the ground track. The area not supported by onsite recovery forces is designated as the contingency landing area. Recovery support for this area is provided by land-based aircraft at staging bases around the world. A landing would be made in the contingency area only as the result of an immediate emergency that would not allow the spacecraft to reach a ship-supported landing area. The ship-supported landing areas lie within or near several recovery zones which are selected prior to a mission. These zones are discussed in detail in the following section.

The end-of-mission landing area is located within one of the recovery zones. This end-of-mission area, called the primary landing area, is well supported by recovery forces — usually an aircraft carrier, helicopters, and search-and-rescue aircraft.

4.0 RECOVERY AREA PLANNING CONSIDERATIONS

4.1 Launch Abort Area

4.1.1 Location of recovery forces.— During the launch phase of a high-inclination mission, the spacecraft will reach higher latitudes than have been reached on previous missions (fig. 1). As stated earlier, recovery support would be required along these ground tracks. The exact location of the launch abort recovery ships and aircraft would depend not only on the orbital inclination, but also on factors such as spacecraft targeting parameters and launch vehicle capabilities.

4.1.2 Weather considerations.— Figures 2 to 6 present data on weather conditions and sea states which can be expected in the launch abort areas over the annual cycle (ref. 1). The term "cumulative percent frequency" (CPF) used in some of the figures designates the percent of the time that a specific parameter does not exceed a set value. It is evident from the figures that winter weather in the higher latitudes presents serious problems. The maximum sea conditions and wind velocities that the command module is designed to withstand are 8-1/2-foot seas and 28-1/2-knot winds. These conditions occur about twice as frequently in the area adjacent to the 50° inclination ground track as in the area along the 32-1/2° inclination ground track. As shown in figure 6, low air temperatures of 56° F can be expected in the 32-1/2° inclination launch abort area, with 45° F in the 40° inclination area, 35° F in the 45° inclination area, and 24° F in the 50° inclination area for midwinter operations.

4.2 Selection of Recovery Zones

Any spacecraft landing from earth orbit, whether it results from an abort, an alternate mission, or a normal mission, is designed to occur within or near a planned recovery zone (although landings could occur anywhere along the spacecraft ground track as a result of an immediate emergency). In selecting the arrangement and size of recovery zones, several factors must be considered. These include the maximum in-orbit wait time that may be allowed for the spacecraft to reach a recovery zone, weather conditions, zone accessibility, and the time that may be allowed for a ship to reach and retrieve the spacecraft and crew after landing (retrieval time). The retrieval time of the recovery ship is relative to the zone size; that is, the larger the zone, the longer it possibly could take a ship in the zone to reach and retrieve a spacecraft landed within the zone. Other considerations in selecting the zone size are illustrated in figure 7.

Table I lists examples of trade-offs that were considered for various recovery zone sizes and arrangements discussed in the following paragraphs. The primary factors used in selecting the optimum recovery zone arrangements are (1) the spacecraft maximum in-orbit wait time, (2) the frequency of occurrence of this wait time, and (3) the recovery forces necessary to support the zones. All of the data in the table were derived from computer-simulated trajectories, map studies, information provided by the Department of Defense, and experience gained from previous earth-orbital missions.

4.2.1 Orbital inclination ($32-1/2^\circ$).— Since several previous manned missions have been flown with orbital inclinations of approximately $32-1/2^\circ$, considerable experience has already been gained in determining optimum zone size and arrangement for this inclination. Therefore, the recovery zone concept for the $32-1/2^\circ$ orbital inclination is a good base with which to compare higher inclination missions. (A mission profile with a 140-nautical-mile-altitude circular orbit and a 14-day duration was used to obtain the data on the following pages.)

Four zones have been used for $32-1/2^\circ$ inclination Gemini and Apollo missions. These zones have usually been centered at or near 28° N 60° W and 28° N 25° W in the Atlantic Ocean, and 28° N 140° E and 28° N 155° W in the Pacific Ocean (zones 1, 2, 3, and 4 in fig. 8); the zone radius has been approximately 240 nautical miles. For a mission profile with a 140-nautical-mile-altitude circular orbit and a 14-day duration, the maximum in-orbit wait for this zone arrangement would be 7.25 hours, occurring five times during the mission. This maximum in-orbit wait has been readily acceptable on past missions and seems applicable in the immediate future. For the remainder of the 14 days, the in-orbit wait would be considerably less, averaging slightly more than 3 hours.

If the recovery zone configuration were decreased to two zones located at Bermuda and Japan (zones 1 and 3 in fig. 8), the maximum in-orbit wait time would increase to 8.75 hours. This wait time would occur once per day and is a significant increase over the four-zone arrangement. However, the majority of the in-orbit waits would still be about 3 hours. If the radius of each of these two zones were increased to 390 nautical miles (zones 5 and 7 in fig. 8), the maximum in-orbit wait would be about the same duration as for the 240-nautical-mile zone configuration, but the wait would occur only about once every other day. The access time, however, would increase because of the increased zone radius. By increasing the number of 390-nautical-mile-radius zones from two to four (zones 5, 6, 7, and 8 in fig. 8), the maximum in-orbit wait time would decrease to 5.7 hours with these periods occurring once per day. The four 240-nautical-mile-radius zones used for Gemini and Apollo missions which had orbital inclinations of approximately $32-1/2^\circ$ presented few problems and provided reasonably acceptable recovery conditions all around.

With the anticipated higher degree of confidence in both the Apollo spacecraft and ground systems, it is expected that increased spacecraft in-orbit waits and increased ship retrieval times will be acceptable. As a result, it would seem possible to employ a two-zone port-centered concept for the landing and recovery of Apollo command modules and their crews. The ideal ports to use in this concept are located in Hawaii and Bermuda (fig. 9), especially since these ports have assigned and readily available search-and-rescue ships.

If two 390-nautical-mile-radius recovery zones centered at the previously manned ports were used, the maximum in-orbit wait for spacecraft in a 140-nautical-mile circular orbit would be about 13 hours, occurring twice in 14 days. If the zone radius were increased to 480 nautical miles, the maximum in-orbit wait would decrease to about 11-1/2 hours, occurring about once per day. The trade-off for this decreased in-orbit wait would be an increase in retrieval time. Therefore, the two-zone port-centered concept requires a spacecraft in-orbit wait about one and three-fourths times as long and a possible retrieval time about twice as long as is provided by the four 240-nautical-mile-radius zones used for the $32-1/2^\circ$ inclination missions.

4.2.2 Orbital inclination (40°).— If four zones (zones 1, 4, 7, and 9 in fig. 10) similar to those used with the $32-1/2^\circ$ inclination missions were to be used for a 40° orbital inclination, the maximum in-orbit wait time would increase slightly from 7.25 to 7.3 hours and would occur about six times in a 14-day mission. If two 240-nautical-mile-radius zones located at Bermuda and in the West Pacific (zones 1 and 8 in fig. 10) were used, the maximum in-orbit wait would increase to 10.2 hours and would occur once per day. For a very short maximum in-orbit wait,

seven 240-nautical-mile-radius zones in the Northern Hemisphere could be used (zones 1, 3, 4, 5, 6, 8, and 12 in fig. 10). Although these zones would provide a maximum in-orbit wait time of 3.5 hours, which would occur 34 times in 14 days, they would be very difficult to support because of the number of ships and aircraft required. Four zones could also be arranged to provide a 3.5-hour-maximum in-orbit wait with these waits occurring 38 times in 14 days (zones 2, 10, 11, and 13 in fig. 10). The zone located off the coast of Chile, however, would be quite difficult to support because of communications and logistics problems.

Using four Northern Hemisphere zones having a 390-nautical-mile-radius (zones 14, 15, 16, and 17 in fig. 10), a maximum in-orbit wait of 7.2 hours, with this period occurring twice in 14 days, could be easily supported. However, with this arrangement retrieval time would increase. Using the zones near Bermuda and Japan only (zones 14 and 16 in fig. 10), the maximum in-orbit wait time would increase to 13.5 hours and would occur twice in 14 days. The four 240-nautical-mile-radius Northern Hemisphere zone concept differs only slightly from that used for the past $32\text{-}1/2^\circ$ inclination orbital missions. The only significant difference is that the zones for the 40° orbital inclination would be centered at a slightly higher latitude.

In the two-zone port-centered concept, the 390-nautical-mile-radius zones centered at Hawaii and Bermuda would provide a maximum in-orbit wait of 11.6 hours, occurring twice in 14 days. By increasing the zone radius to 480 nautical miles, the maximum in-orbit wait decreases to 10.1 hours, occurring once per day, but the maximum ship retrieval time increases. This port-centered concept is very similar to the one discussed for the $32\text{-}1/2^\circ$ inclination orbit.

4.2.3 Orbital inclination (45°).— For a 45° orbital inclination, weather problems increase when the recovery zones are arranged at higher latitudes for optimum orbital coverage. Therefore, it is desirable to keep the planned recovery zones within a latitude band from 40° N to 40° S. To remain in the 40° N to 40° S band and still maintain adequate orbital coverage, at least 390-nautical-mile-radius zones are required. Unfortunately, the zone size increase also causes an increase in the maximum allowable retrieval time.

If four zones are located close to the same four zones employed with the $32\text{-}1/2^\circ$ inclination missions (zones 1, 2, 3, and 5 in fig. 11), a maximum in-orbit wait of 4.5 hours, occurring about once per day, results. If only the Bermuda and Japan zones are used (zones 1 and 3 in fig. 11), the maximum in-orbit wait would increase to 7.5 hours, occurring once per day. Using five zones (zones 1, 2, 3, 5, and 8 in fig. 11), the maximum wait time would be 4.0 hours, occurring once per day. (However, zone 8 is off the coast of Chile and would be difficult to support.) By increasing the zones to six (zones 1, 2, 4, 5, 6, and

7 in fig. 11), the maximum in-orbit wait time could be reduced to 3.25 hours, with the wait periods occurring twice per day. Only one of these zones would be in the Southern Hemisphere (off New Zealand). The southern zone could be supported, but extensive transit time to the zone would have to be allowed. The North Pacific zones would require oiler-type ship support because of the extended range to station.

The four zone concept for the 45° orbital inclination differs only slightly from the four zone concept for the 40° and $32\text{-}1/2^\circ$ orbital inclinations and could easily be used with a high degree of confidence. The main difference is in the increased zone size and the increased retrieval time for the 45° orbital inclination.

For the two-zone port-centered concept, which is very similar to the one for the $32\text{-}1/2^\circ$ orbital inclination, the 390-nautical-mile-radius zones at Hawaii and Bermuda would result in a maximum in-orbit wait of 16.1 hours, occurring twice in 14 days. If the zone radius were increased to 480 nautical miles, the maximum in-orbit wait would decrease to 10.1 hours, occurring seven times in 14 days.

4.2.4 Orbital inclination (50°).— The recovery zone concepts for a mission having a 50° inclination are similar to those for a mission having a 45° inclination. The maximum spacecraft in-orbit wait would generally increase, but the zone radius would remain at least at 390 nautical miles.

For an eight-zone concept using zones 1, 2, 3, 5, 6, 7, 8, and 9 in figure 12, the maximum in-orbit wait time would be 3 hours, with the maximum wait periods occurring 10 times in 14 days. This zone arrangement is supportable; however, an extensive number of ships would be required for the Pacific zones. This would be undesirable from a logistics point of view.

A six-zone concept (zones 1, 2, 4, 6, 9, and 10 in fig. 12) would allow a maximum in-orbit wait of 4.5 hours, occurring 10 times in 14 days. There would be two North Atlantic zones, three North Pacific zones, and one South Pacific zone. The South Pacific zone (off Chile) would be the most difficult to support.

With 5 zones (zones 1, 2, 4, 6, and 9 in fig. 12), the maximum in-orbit wait time would be 5.7 hours. Wait periods of this duration would occur three times in 14 days. All of these zones are supportable.

A four-zone concept (zones 1, 2, 3, and 8 in fig. 12) would provide a maximum in-orbit wait time of 5.0 hours, occurring once per day. Of the four, two would be in the North Atlantic, off Bermuda and the Canary Islands, and two would be in the North Pacific, off Japan and Hawaii. All four zones could be supported.

For a two-zone concept (zones 1 and 3 in fig. 12), zones would be located off Japan and Bermuda. Both of these zones could be supported. The maximum in-orbit wait time for this arrangement would be 7.9 hours, with these wait periods occurring twice per day.

The two-zone port-centered arrangement for the 50° orbital inclination is the same as that described for the $32\frac{1}{2}^\circ$, 40° , and 45° orbital inclinations. For the 390-nautical-mile-radius zones, the maximum spacecraft in-orbit wait would be 16.1 hours, occurring twice in 14 days. For the 480-nautical-mile-radius zones, a maximum in-orbit wait of 10.1 hours would occur four times in 14 days.

4.3 Weather Considerations in Secondary and Contingency Landing Areas

4.3.1 Recovery zones.— By constraining the recovery zone locations to within the 40° N to 40° S latitude band for orbital inclinations between 40° and 50° , most unfavorable weather conditions are avoidable, as is indicated in figures 13 to 18. Also, it is considered unlikely that equally severe weather will occur in two or more recovery zones within the same timespan. Therefore, no appreciable constraint because of weather is placed on planning recovery zone locations for the missions under consideration.

4.3.2 Contingency landing area.— Because contingency landings can occur almost anywhere along the spacecraft ground track, a spacecraft could land in very severe weather for the high-inclination missions. If emergency landings in the contingency area are to be provided for, the spacecraft and survival equipment would be required to withstand the adverse weather found at the higher latitudes. These requirements are discussed in the following section.

5.0 POSTLANDING SYSTEMS AND RECOVERY EQUIPMENT

5.1 General

The Apollo command module equipment utilized in recovery operations currently consists of the command module structure, the uprighting subsystem, the postlanding batteries, the vhf recovery beacon, the vhf/AM transceivers, the survival beacon-transceiver, the vhf antennas, the postlanding ventilation subsystem, and the crew survival equipment. The recovery equipment consists of the Apollo flotation collar, the davit retrieval crane, and the pararescue equipment (ref. 2). This equipment is discussed in the following paragraphs and the conditions under which these systems have been evaluated are summarized in table II.

5.2 Command Module

5.2.1 Structure.- Wave height and windspeed are basic considerations in establishing design criteria for the structural integrity of the command module during the postlanding phase of a mission. Current design criteria limits landing and recovery to conditions of 8-1/2-foot seas and 28-1/2-knot winds. It is probable that the Apollo command module design limits on winds and waves would be exceeded with landings in the launch abort or contingency landing areas for the higher inclination missions under consideration. This is particularly true for landings that might occur during the winter months. Water and air temperatures should present no structural constraints. However, some further structural testing for resistance to waves and winds might be necessary before a high-inclination mission is flown.

5.2.2 Uprighting subsystem.- This subsystem has also been qualified to withstand 8-1/2-foot seas and 28-1/2-knot winds. Individual components have been tested in a dry environment from 0° to 90° F with no adverse effects. No testing of the subsystem assembly has occurred at sea with temperatures at or near freezing. Even though no difficulty with the uprighting subsystem is expected with temperatures around 32° F, some further qualification might be necessary for the landing environments encountered at higher latitudes.

5.2.3 Postlanding batteries.- Temperature is the major environmental factor that affects the batteries. With lowering of the temperature to the minimum that would be encountered in the launch abort or contingency landing areas, the battery output will decrease from the nominal; however, the difference in available power is not sufficient to hamper survival or recovery location. No problems are expected with the postlanding batteries for missions with inclinations up to 50°.

5.2.4 Communication equipment and location aids.- The communication equipment and location aids consist of the vhf recovery beacon, the vhf/AM transceivers, the survival beacon-transceiver, and the associated antennas. The solid-state components of this equipment are affected primarily by temperature only. The vhf recovery beacon has been functionally tested from 50° to 135° F and operational tests have been performed on the recovery beacon at temperatures between 70° and 118° F. Therefore, no operational experience has occurred with this equipment in the potential temperature range (24° to 70° F) expected in the launch abort areas. The vhf/AM transceivers and the survival beacon-transceiver have been operationally qualified in temperatures from 32° to 140° F. This essentially includes the range of temperatures expected at landing. The vhf antennas are mainly affected by wind and wave action. Damage to the antennas is likely to occur if landing conditions exceed the

design limits of 8-1/2-foot waves and 28-1/2-knot winds. Ice formation on the antennas does degrade their functioning. In general, further testing and development seem necessary for the communication equipment and location aids for possible high-inclination long-duration missions.

5.2.5 Postlanding ventilation subsystem.- Postlanding environmental control is effected primarily by the postlanding ventilation subsystem, which provides both cooling of the command module and CO₂ removal from the cabin by air exchange. The outside-air temperature is the primary environmental consideration affecting the subsystem. A computer analysis indicates that, with the crew inside and unsuited, and using a 20-minute ON and 40-minute OFF cycle, the postlanding ventilation subsystem provides a command module inside temperature varying between 46° and 83° F, as well as adequate removal of CO₂ with an outside-air temperature of 35° F. The subsystem has not been operationally investigated in air temperatures below 69° F and will require further testing before cold weather operations.

5.2.6 Survival equipment.- The survival equipment was designed for tropical and semitropical waters. No equipment is currently available in the crew survival container for cold weather conditions. Such equipment will have to be made available.

5.3 Recovery Equipment

5.3.1 Apollo flotation collar.- The Apollo flotation collar has been functionally checked in 50° F air and water temperatures. Operational experience with the Apollo flotation collar has been gained primarily under temperature conditions higher than 50° F. The inflation cylinders are currently filled with 11.0 pounds of CO₂ for nominal collar inflation. The CO₂ cylinders have a capacity of 12.6 pounds. If the cylinder is filled to maximum capacity, the CO₂ should provide sufficient pressure for proper inflation at a temperature of 35° F. The cylinders would be only partially emptied for higher temperature operation.

The major problem associated with the flotation collar inflation is that CO₂ freezes in the fill tube between the cylinder and the collar. This problem could be overcome with design modifications to the collar. The collar material is affected very little by the temperature range expected in the landing areas. With high wind and wave conditions, the swimmers will have difficulty swimming to the command module and securing the collar to it. Also, lower temperature operation will increase the collar installation time because swimmers will be required

to wear heavier hand coverings and bulkier suits. However, there should be no problem in installing the collar once it has been secured to the command module since only whole-hand grasping motions are required in manipulating the collar attachments.

5.3.2 Shipboard recovery equipment.- Destroyers equipped with davit cranes are usually positioned in the launch abort landing areas for command module retrieval if an abort were to occur. No formalized test program for davit crane operations in low temperatures has been conducted. However, various training and development tests have been conducted in freezing and near-freezing temperatures. From a design viewpoint, no hardware would be damaged either mechanically or electrically by low-temperature operation, but icing of the crane exterior could present minor problems. If icing conditions do occur, the ice could be removed and normal operations continued. Testing has been conducted aboard U.S. Navy destroyers and the NASA Motor Vessel Retriever in wind and wave conditions in excess of design limits. In high winds and seas, recovery becomes considerably more difficult, and the likelihood of damage to the command module and the recovery ship increases. Therefore, the training required for operators of davit cranes and the ship personnel assigned to command module handling tasks will be greatly increased.

5.3.3 Pararescue equipment.- Pararescue operations are suitable for almost all climatic conditions likely to be encountered at the landing sites. With expected lower air and water temperatures, heavier protective suits and thicker hand and foot coverings will be required; however, this is standard pararescue equipment. As the temperature decreases, in-water time will have to be proportionately reduced. At 28° F air temperature and 35° F water temperature, each pararescue swimmer can remain in the water for approximately 20 minutes before having to return to the cold weather survival raft.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the analysis upon which this paper is based indicate that recovery of Apollo command modules following missions with inclinations of 32-1/2° to 50° is feasible. It is desirable, however, to have the landing occur in favorable weather conditions. These usually prevail within the 40° N to 40° S latitude band. Planned landing zones, both primary and secondary, can be provided within this band for inclinations between 32-1/2° to 50°. The launch abort areas are essentially fixed by the launch inclination. Therefore, inclinations above 40° begin to present problems of wind, waves, and low temperatures at the higher latitudes. This is especially a problem during the winter months. Therefore, for the higher launch inclinations, summer launch dates are

desirable. If a winter launch is scheduled, slippage due to weather difficulties in the launch abort areas should be considered. Little can be done to provide support for a contingency landing other than the current practice of employing standby recovery forces.

In-orbit coverage can be obtained by several recovery zone combinations for each mission inclination. The four-zone concept provides a reasonable configuration for each of the inclinations investigated, but the long durations planned for these missions require an extensive (about twofold) increase in the number of ships necessary for recovery operations. This four-zone concept, however, does provide an adequate trade-off between in-orbit wait time, spacecraft retrieval time, weather conditions, and zone accessibility. These zones are located near Bermuda, the Canary Islands, Japan, and Hawaii, and are between 20° N and 40° N. All are in easily supported locations. The recovery zones for the $32\text{-}1/2^{\circ}$ and 40° missions would be 240 nautical miles in radius. The 45° and 50° zones would require 390-nautical-mile-radius zones for adequate orbital coverage. Weather in these recovery zones would be reasonable for the most part. The weather conditions in the recovery zones for the 40° , 45° , and 50° orbital inclination missions would average about the same in severity. Equal conditions occurring in all four zones simultaneously would be unlikely; therefore, the best zone could be selected if the required in-orbit wait were acceptable. The average weather conditions in the $32\text{-}1/2^{\circ}$ zones would be less severe because of the more equatorial zone locations.

During the long-duration missions, however, supporting four recovery zones with ships remaining at sea for a period of 2 months or more would become very impractical, both economically and logistically; therefore, the two-zone port-centered concept should be utilized. These two zones are centered at Hawaii and Bermuda and are very easily supported. The zone sizes depend upon the ship access times and spacecraft in-orbit waits (table I) that are acceptable. Again, weather in these zones is reasonable.

Because all spacecraft recoveries to date, as well as operational qualification tests, have been conducted in warm air and water conditions, a test program to evaluate cold weather recovery operations should be considered. A cold weather test program would provide a basis for possible changes in equipment and procedures, as well as provide operational experience.

In conclusion, the high-inclination long-duration missions planned for possible use of Apollo equipment should permit in-orbit waits approaching 12 hours or longer. The command module postlanding systems and the recovery equipment should be designed to withstand the environment at the higher latitudes (up to 50° N and 50° S); and, finally, the spacecraft planned landing areas should not be located outside the 40° N to 40° S latitude band.

7.0 REFERENCES

1. Spaceflight Meteorology Group, Manned Spacecraft Center, NASA:
Marine Climatic Guide. Jan. 1968.
2. Bass, Roderick S.; O'Briant, Thomas E.; and Hirasaki, John K.:
Manned Spacecraft Center, NASA, Postlanding Systems Analysis
of the Apollo 50° Inclination Missions, Study 67-180. July 1967.

TABLE I.- RECOVERY ZONES INVESTIGATED^a
 [Data based on circular orbits of 140-nautical-mile altitude]

(a) On-site ship support concept

Orbital inclination, deg	Radius, n. mi.	Number of zones	Zone description			Maximum in-orbit wait time, hr	Number of times maximum in-orbit wait occurs in 14 days	Recovery zone rating (c)			
			Arrangement	Centers ^b							
				Lat	Long.						
32.5	240	4	2 in N Atlantic	28° N	60° W	7.25	5	B			
			2 in N Pacific	28° N	25° W						
		2	1 in N Atlantic	28° N	140° E				8.75	14	A-
			1 in N Pacific	28° N	155° W						
	4	2 in N Atlantic	26° N	60° W	5.7	14	B				
		2 in N Pacific	26° N	25° W							
40.0	390	2	1 in N Atlantic	26° N				140° E	8.7	8	A-
			1 in N Pacific	26° N				155° W			
		4	1 in N Atlantic	36° N	56° W	3.5	38	C+			
			1 in N Pacific	36° N	159° W						
	4	2 in S Pacific	36° S	175° W	7.3				6	B	
		2 in S Pacific	36° S	83° W							
	240	4	2 in N Atlantic	36° N		60° W	10.2	14			A-
			2 in N Pacific	36° N		14° W					
		2	1 in N Atlantic	36° N	146° E	3.5			34	D+	
			1 in N Pacific	36° N	175° W						
		7	1 in N Atlantic	36° N	60° W		3.5	34			D+
			1 in N Pacific	36° N	155° E						
	3 in N Atlantic		36° N	60° W	3.5	34			D+		
			3 in N Atlantic	36° N						14° W	
4 in N Pacific	10° N	25° W	3.5	34			D+				
	4 in N Pacific	30° N						138° E			
4 in N Pacific	36° N	155° E			3.5	34		D+			
	4 in N Pacific	36° N							128° W		
4 in N Pacific	17° N	138° E	3.5	34			D+				
	4 in N Pacific	17° N							138° E		

^aThe recovery zones listed were judged to be the most suitable based on orbital coverage and zone weather.

^bAll zone centers are approximate and are for study purposes only.

^cSee part C of table for criteria and rating scale.

^dNew Zealand and Chile.

TABLE I.- RECOVERY ZONES INVESTIGATED^a - Continued
[Data based on circular orbits of 140-nautical-mile altitude]

(a) On-site ship support concept - Continued

Orbital inclination, deg	Radius, n. mi.	Zone Description			Maximum in-orbit wait time, hr	Number of times maximum in-orbit wait occurs in 14 days	Recovery zone rating (c)
		Number of zones	Arrangement	Centers ^b Lat Long.			
40.0	390	4	2 in N Atlantic	33° N 62° W 33° N 19° W	7.2	2	B
			2 in N Pacific	31° N 145° E 33° N 175° W			
		2	1 in N Atlantic	33° N 62° W	13.5	2	A-
			1 in N Pacific	31° N 145° E			
45.0	390	6	2 in N Atlantic	33° N 62° W 33° N 19° W	3.25	28	D
			3 in N Pacific	33° N 175° W 33° N 130° W 33° N 162° E			
			1 in S Pacific	33° S 167° W			
		5	2 in N Atlantic	33° N 62° W 33° N 19° W	4.0	14	C
			2 in N Pacific	31° N 145° E 33° N 175° W			
			1 in S Pacific	25° S 87° W			
		4	2 in N Atlantic	33° N 62° W 33° N 19° W	4.5	14	B
			2 in N Pacific	31° N 145° E 33° N 175° W			
50.0	390	2	1 in N Atlantic	33° N 62° W	7.5	14	A-
			1 in N Pacific	31° N 145° E			
		8	2 in N Atlantic	33° N 64° W 33° N 23° W	3.0	10	D-
			3 in N Pacific	33° N 166° E 33° N 175° W 33° E 152° W			
			1 in S Pacific	33° S 170° W			
			1 in S Pacific	33° S 170° W			

^aThe recovery zones listed were judged to be the most suitable based on orbital coverage and zone weather.

^bAll zone centers are approximate and are for study purposes only.

^cSee part C of table for criteria and rating scale.

^dNew Zealand and Chile.

TABLE I.- RECOVERY ZONES INVESTIGATED^a - Continued
 [Data based on circular orbits of 140-nautical-mile altitude]

(a) On-site ship support concept - Concluded

Orbital inclination, deg	Zone description					Recovery zone rating (c)	
	Radius, n. mi.	Number of zones	Arrangement	Centers ^b			
				Lat	Long.		
50.0	390	6	2 in N Atlantic	33° N	64° W	4.5	D
				33° N	23° W		
			3 in N Pacific	33° N	175° W		
				33° N	130° W		
			1 in S Pacific	33° S	80° W		
	390	5	2 in N Atlantic	33° N	64° W	5.7	B-
				33° N	23° W		
			3 in N Pacific	33° N	175° W		
				33° N	130° W		
				33° N	154° E		
	480	4	2 in N Atlantic	33° N	64° W	5.0	B
				33° N	23° W		
			2 in N Pacific	33° N	147° E		
				33° N	152° W		
	480	2	1 in N Atlantic	33° N	64° W	7.9	A-
			1 in S Pacific	33° N	147° E		

(b) Two-zone in-port ship support concept

Orbital inclination, deg	Zone description					Maximum in-orbit wait time, hr	Number of times maximum in-orbit wait occurs in 14 days	Recovery zone rating (c)
	Radius, n. mi.	Arrangement	Centers ^b					
			Lat	Long.				
32.5	390	Hawaii	21.33° N	157.95° W	13.15	2	A	
		Bermuda	32.28° N	64.83° W				
	480	Hawaii	21.33° N	157.95° W	11.6	14	A	
		Bermuda	32.28° N	64.83° W				
40.0	390	Hawaii	21.33° N	157.95° W	11.6	2	A	
		Bermuda	32.28° N	64.83° W				
	480	Hawaii	21.33° N	157.95° W	10.1	14	A	
		Bermuda	32.28° N	64.83° W				

^aThe recovery zones listed were judged to be the most suitable based on orbital coverage zone weather.

^bAll zone centers are approximate and are for study purposes only.

^cSee part C of table for criteria and rating scale.

^dNew Zealand and Chile.

TABLE I.- RECOVERY ZONES INVESTIGATED^a - Continued
 [Data based on circular orbits of 140-nautical-mile altitude]
 (b) Two-zone in-port ship support concept - Concluded

Orbital inclination, deg	Zone description				Maximum in-orbit wait time, hr	Number of times maximum in-orbit wait occurs in 14 days	Recovery zone rating (c)
	Radius, n. mi.	Arrangement	Centers ^b				
			Lat	Long.			
45.0	390	Hawaii Bermuda	21.33° N 32.28° N	157.95° W 64.83° W	16.1	2	A
	480	Hawaii Bermuda	21.33° N 32.28° N	157.95° W 64.83° W	10.1	7	A
50.0	390	Hawaii Bermuda	21.33° N 32.28° N	157.95° W 64.83° W	16.1	2	A
	480	Hawaii Bermuda	21.33° N 32.28° N	157.95° W 64.83° W	10.1	4	A

^aThe recovery zones listed were judged to be the most suitable based on orbital coverage and zone weather.

^bAll zone centers are approximate and are for study purposes only.

^cSee part C of table for criteria and rating scale.

^dNew Zealand and Chile.

TABLE I.- RECOVERY ZONES INVESTIGATED^a - Continued

[Data based on circular orbits of 140-nautical-mile altitude]

(c) Recovery zone rating

Rating	Criteria
A	Two zones No ships at sea Nonmission committed recovery ships and aircraft Acceptable year-round weather All zones in Northern Hemisphere
A-	Two zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather All zones in Northern Hemisphere
B	Four zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather All zones in Northern Hemisphere
B-	Five zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather All zones in Northern Hemisphere
C+	Four zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather Zones in Northern and Southern Hemispheres

TABLE I.- RECOVERY ZONES INVESTIGATED^a - Concluded
 [Data based on circular orbits of 140-nautical-mile altitude]

(c) Recovery zone rating - Concluded

Rating	Criteria
C	Five zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather Zones in Northern and Southern Hemispheres
D+	Seven zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather All zones in Northern Hemisphere
D	Six zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather Zones in Northern and Southern Hemispheres
D-	Eight zones Ships at sea Ships and aircraft committed for mission duration up to 56 days Acceptable year-round weather Zones in Northern and Southern Hemispheres

TABLE II.- POSTLANDING SYSTEMS EVALUATION

Items evaluated	Specification temperatures of		System test temperatures of		Specification wave heights (trough to crest), ft	System test wave heights (trough to crest), ft	Specification wind speeds, knots	System test wind speeds, knots	Remarks
	Minimum	Maximum	Minimum	Maximum					
Spacecraft structure	--	--	--	--	^a 8-1/2	^a 12	^a 28-1/2	^a 24	The spacecraft structure should not be affected by the landing impact or sea conditions.
Uprighting subsystem	0	^b 250	0	^b 90	^a 0 to 8-1/2	^a 0 to 12	^a 28-1/2	^a 24	Have assist in initial uprighting. Conditions within specification should not affect uprighting, especially if the temperature remains above freezing.
Postlanding batteries	50	^c 95	50	^a 89	--	--	--	--	The battery performance will not be affected for the expected operational temperature.
vhf recovery beacon	50	^c 135	70	^a 118	--	--	--	--	The system met a 75° F temperature operation for 8 hours. Lower temperature operation should be investigated.
Survival beacon-transceiver	32	^c 140	32	^b 140	--	--	--	--	Low-temperature operation was for the required 4 hours specified.
vhf/AM transceiver	32	^c 135	35	^b 140	--	--	--	--	The package was tested under these conditions for 8 hours. No additional testing is foreseen.
vhf antennas	--	--	--	--	8-1/2	--	28-1/2	--	Temperature should not affect operation so long as ice formation does not occur.
Postlanding ventilation subsystem	50	^a 90	69	^b 92	--	--	--	--	PLY operation should be unaffected down to freezing temperatures. Habitability of the spacecraft may be marginal.
Apollo flotation collar	--	--	50	^b 80	8-1/2	^b 10	28-1/2	^b 20	The collar seems adequate for operations down to freezing, though slight changes may be required.
Davit retrieval crane	--	--	--	--	8-1/2	^b 12	28-1/2	^a 25	The davit crane appears adequate for the higher latitude environmental conditions, although design changes may be required to facilitate handling Apollo spacecraft.

^a Operating environment.^b Dry air.^c Functional.^d Nonoperational.

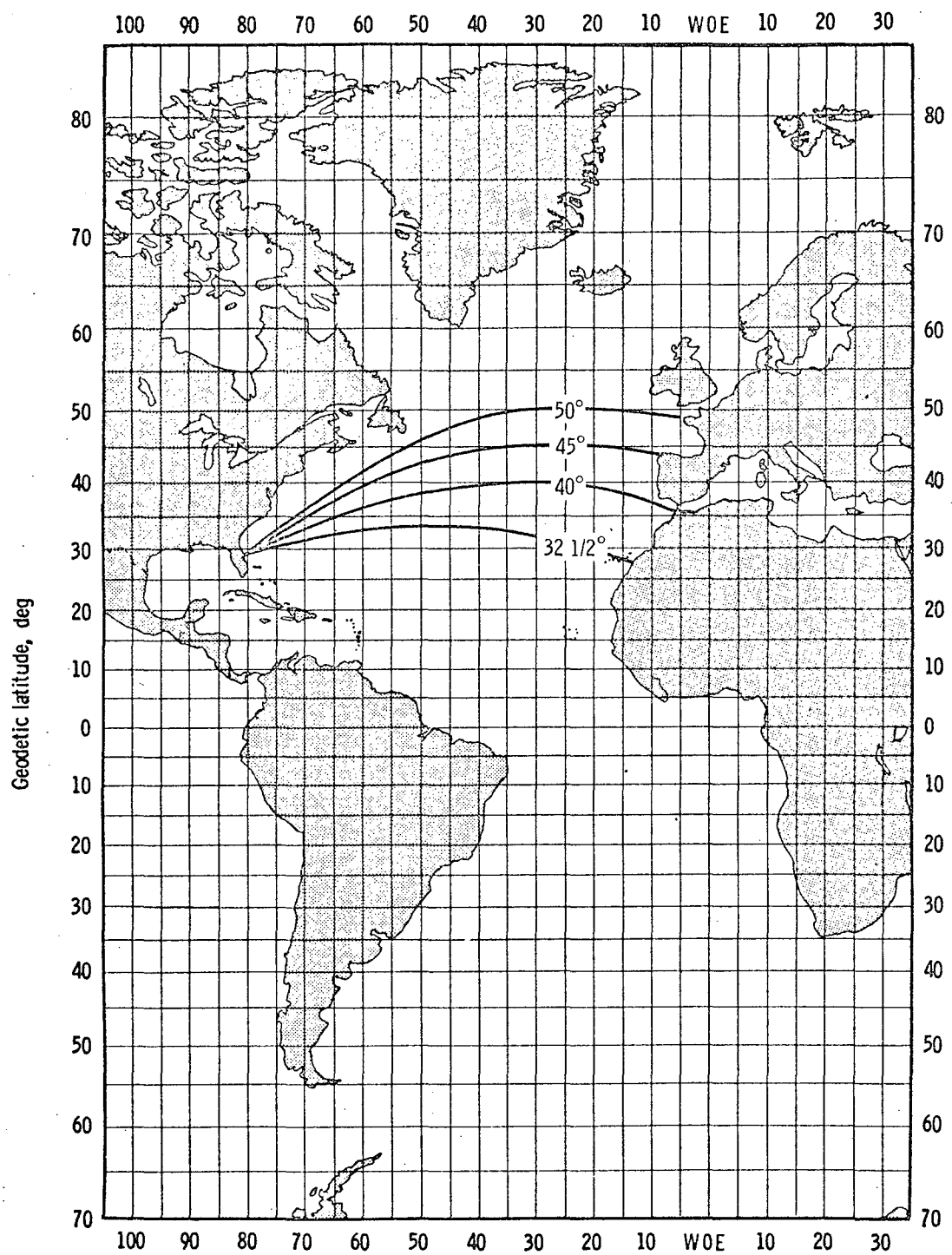


Figure 1. - Launch abort areas for various orbital inclinations.

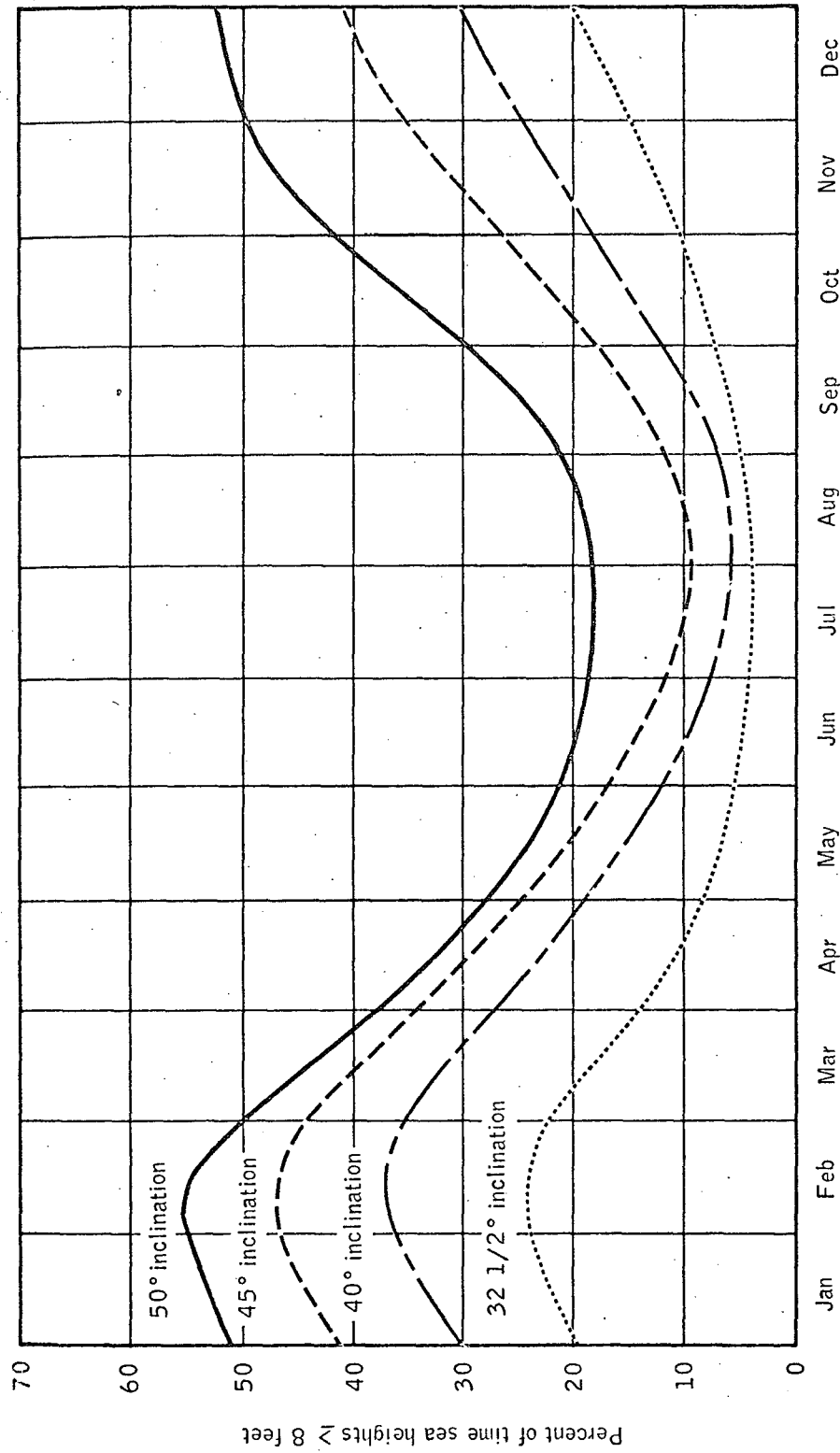


Figure 2.- Percent of time sea heights equal or exceed 8 feet in launch abort areas.

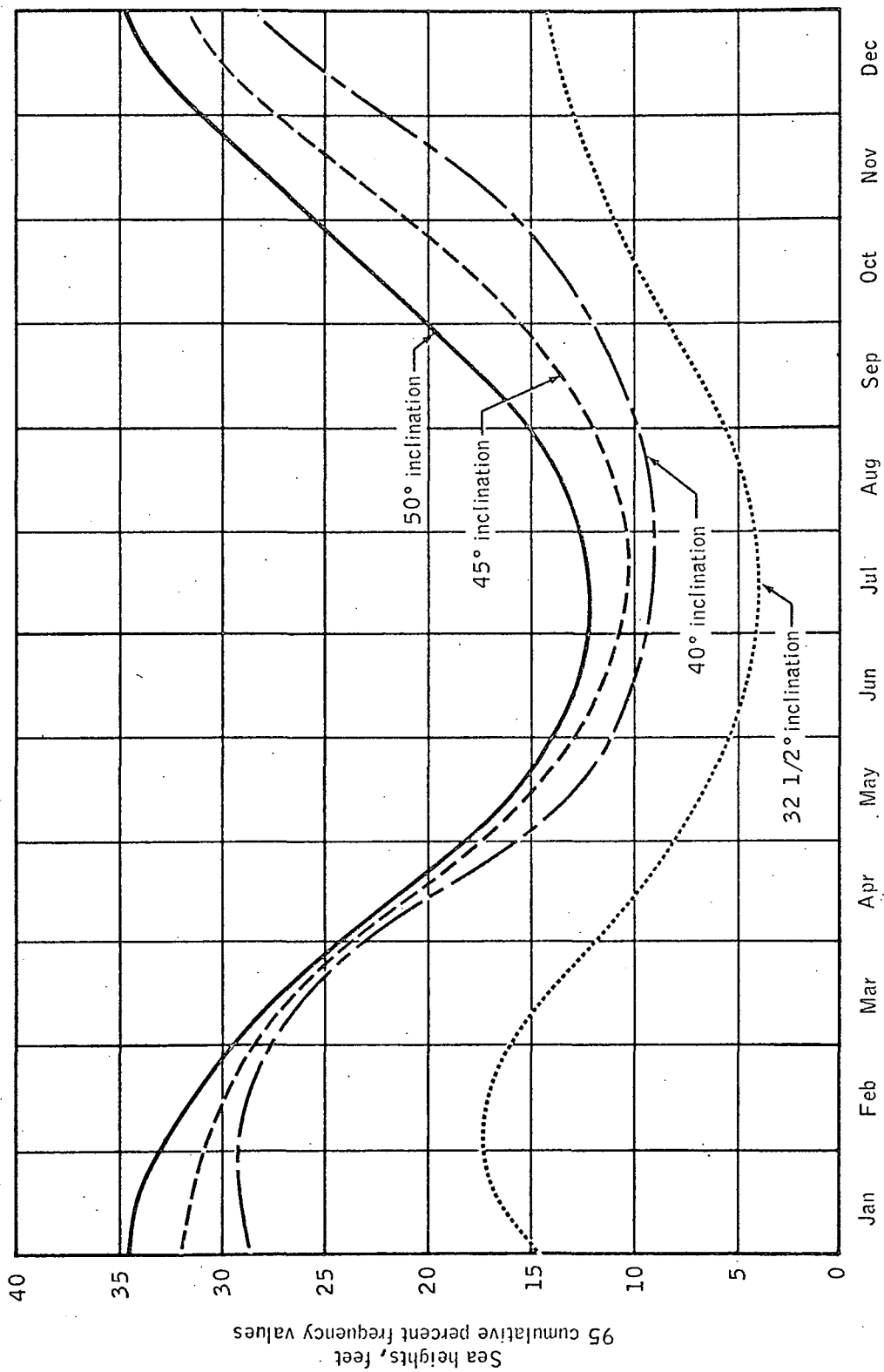


Figure 3.- Sea heights in launch abort areas.

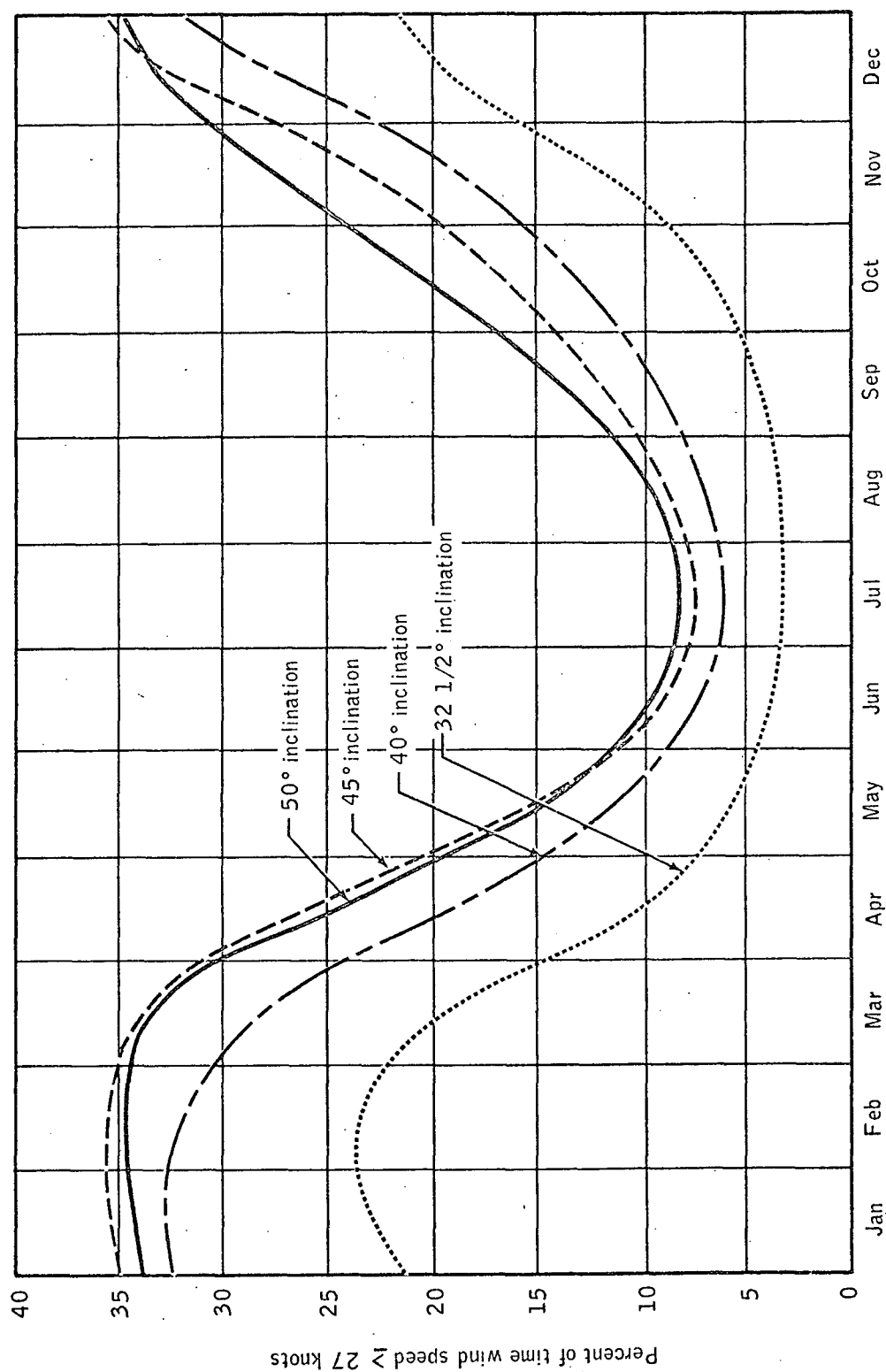


Figure 4.- Percent of time wind speed equals or exceeds 27 knots in launch abort areas.

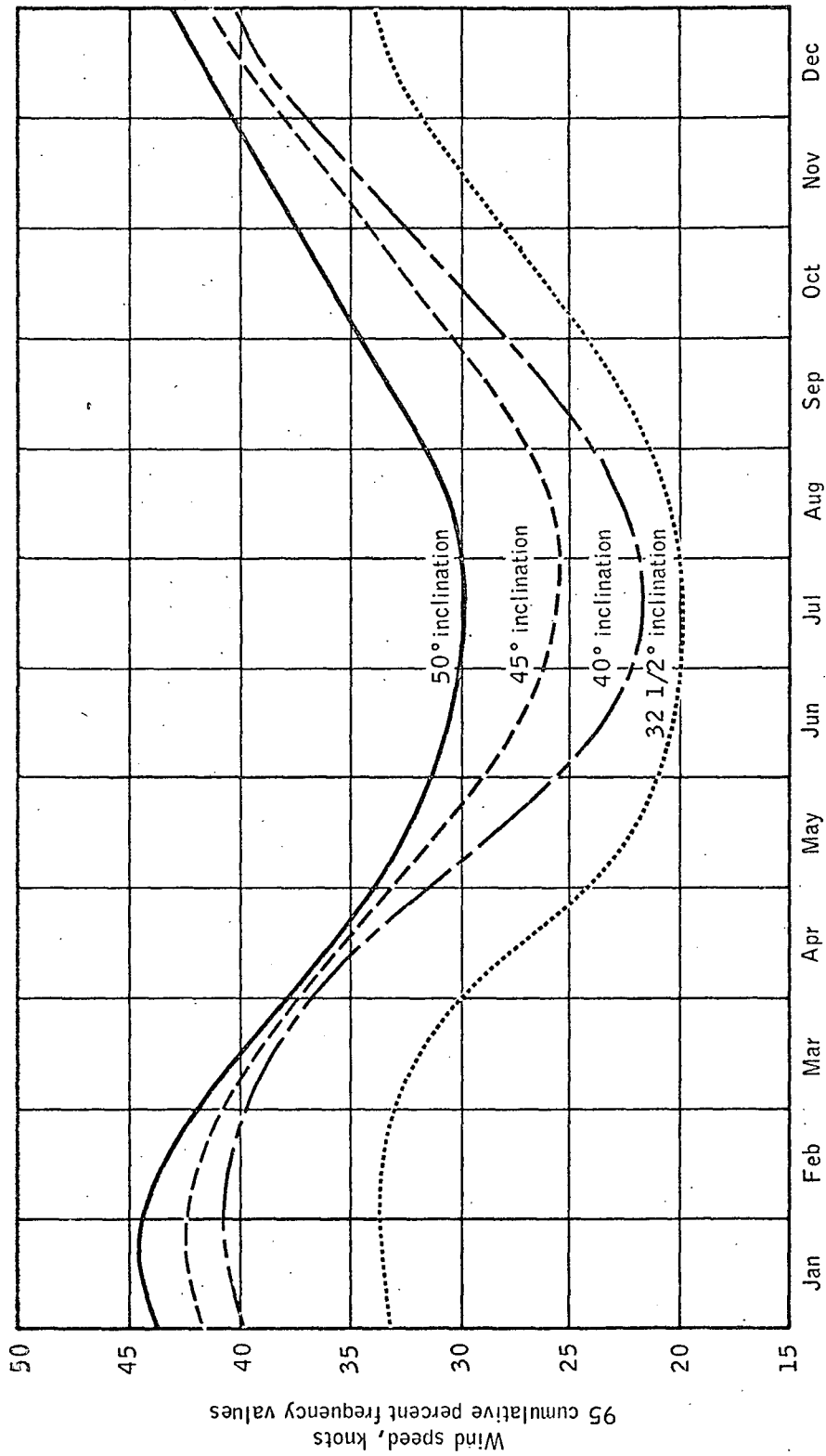


Figure 5.- Wind speed in launch abort areas.

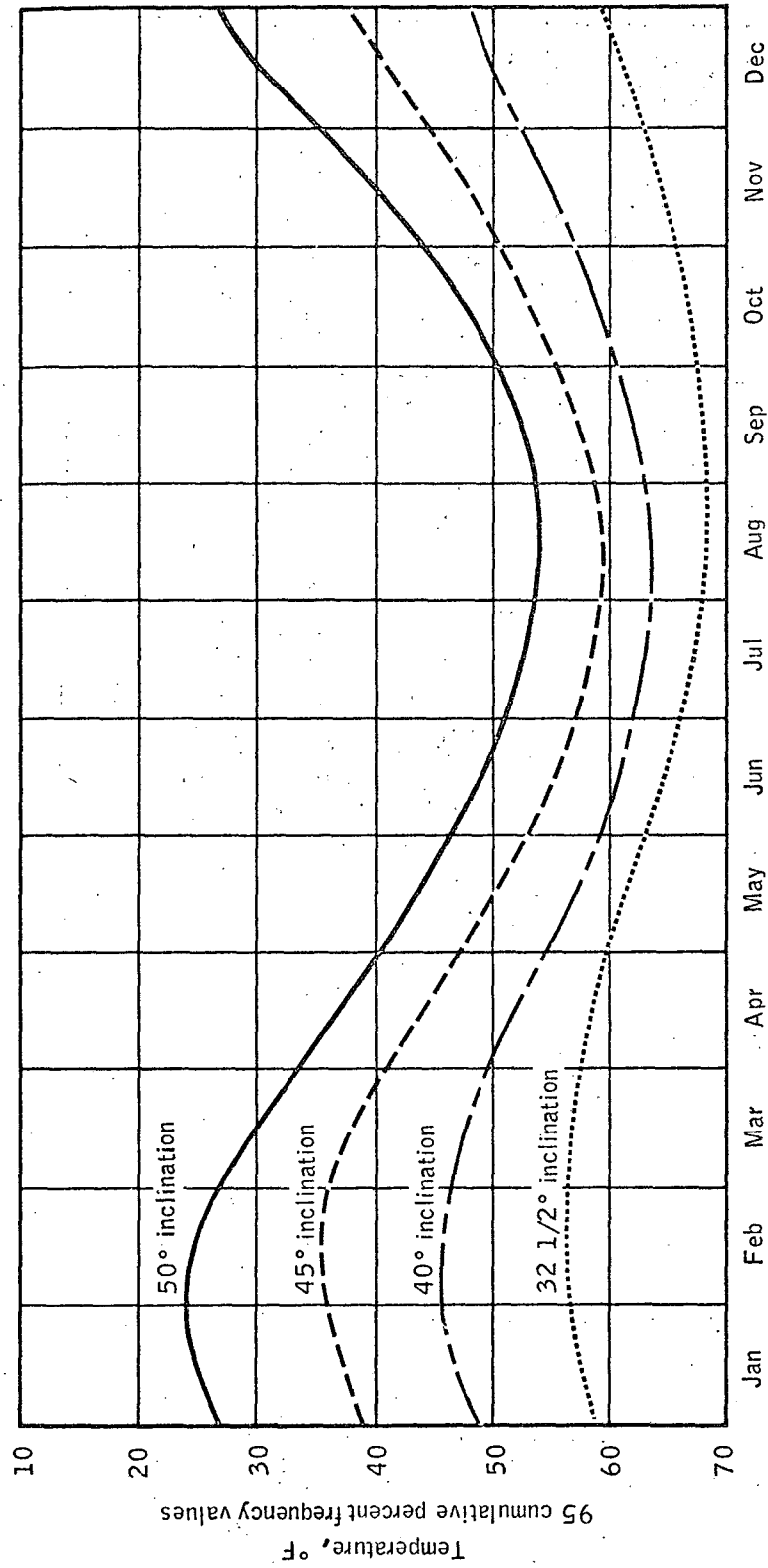
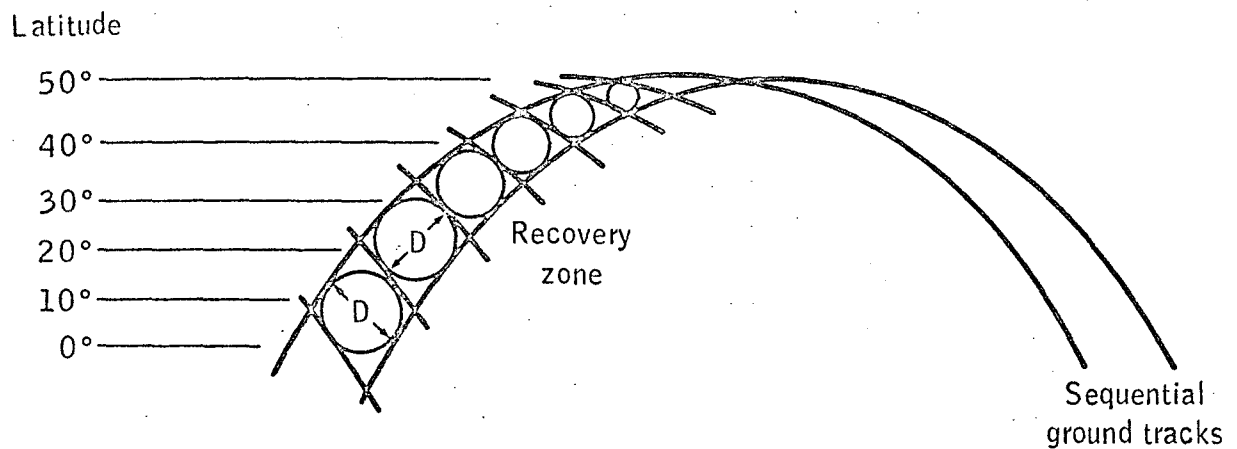


Figure 6.- Minimum temperatures in launch abort areas.



To provide optimum recovery zone size, the zone diameter must be equal to the perpendicular distance between two successive ground tracks. This results in each recovery zone covering four orbits per day. To reduce the ship access time to reasonable limits it is often necessary to move the zone from the equator as is shown in the diagram.

Figure 7.- Determination of recovery zone size.

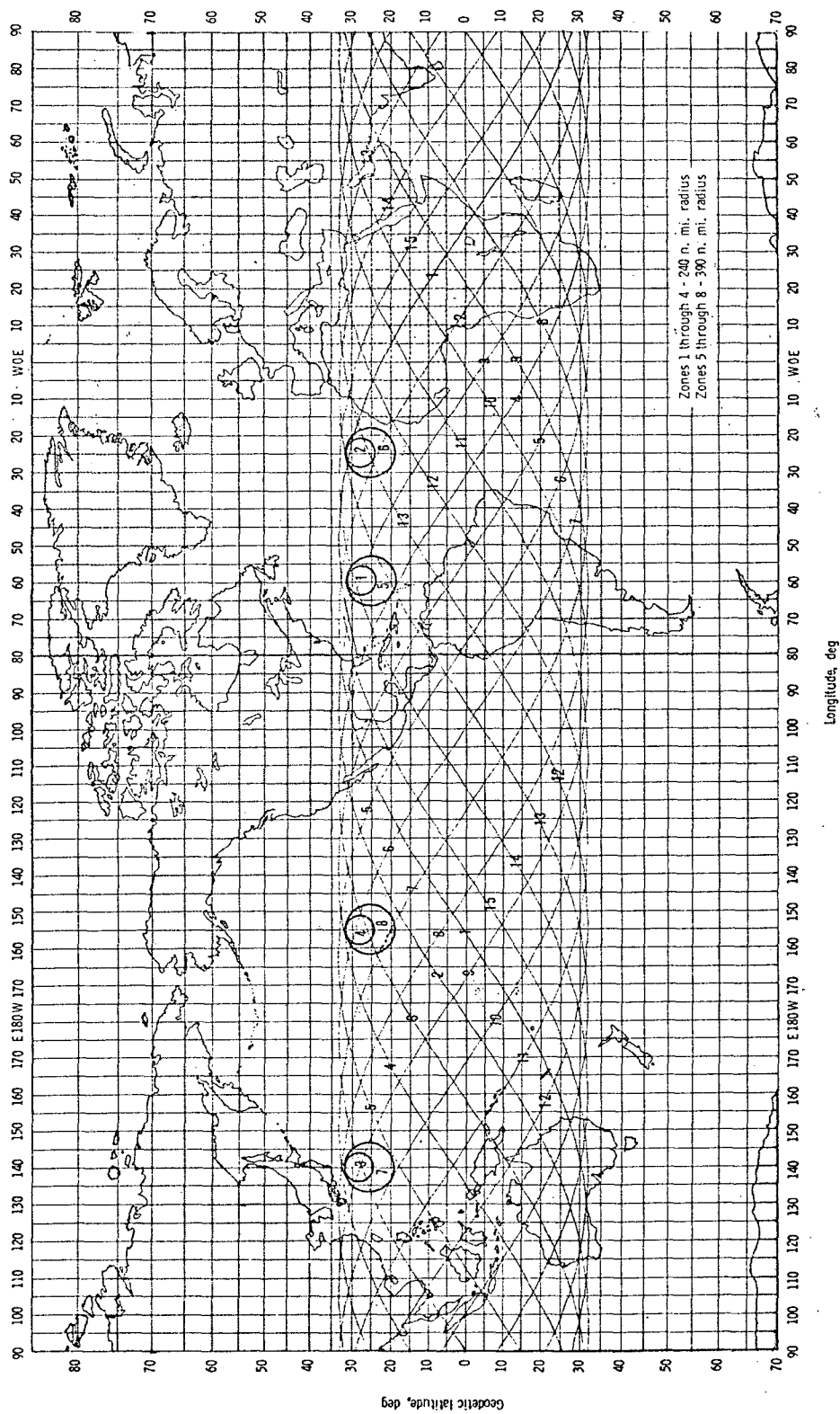


Figure 8. - Recovery zones considered for 32 1/2° inclination orbit circularized at 140 n. mi. altitude.

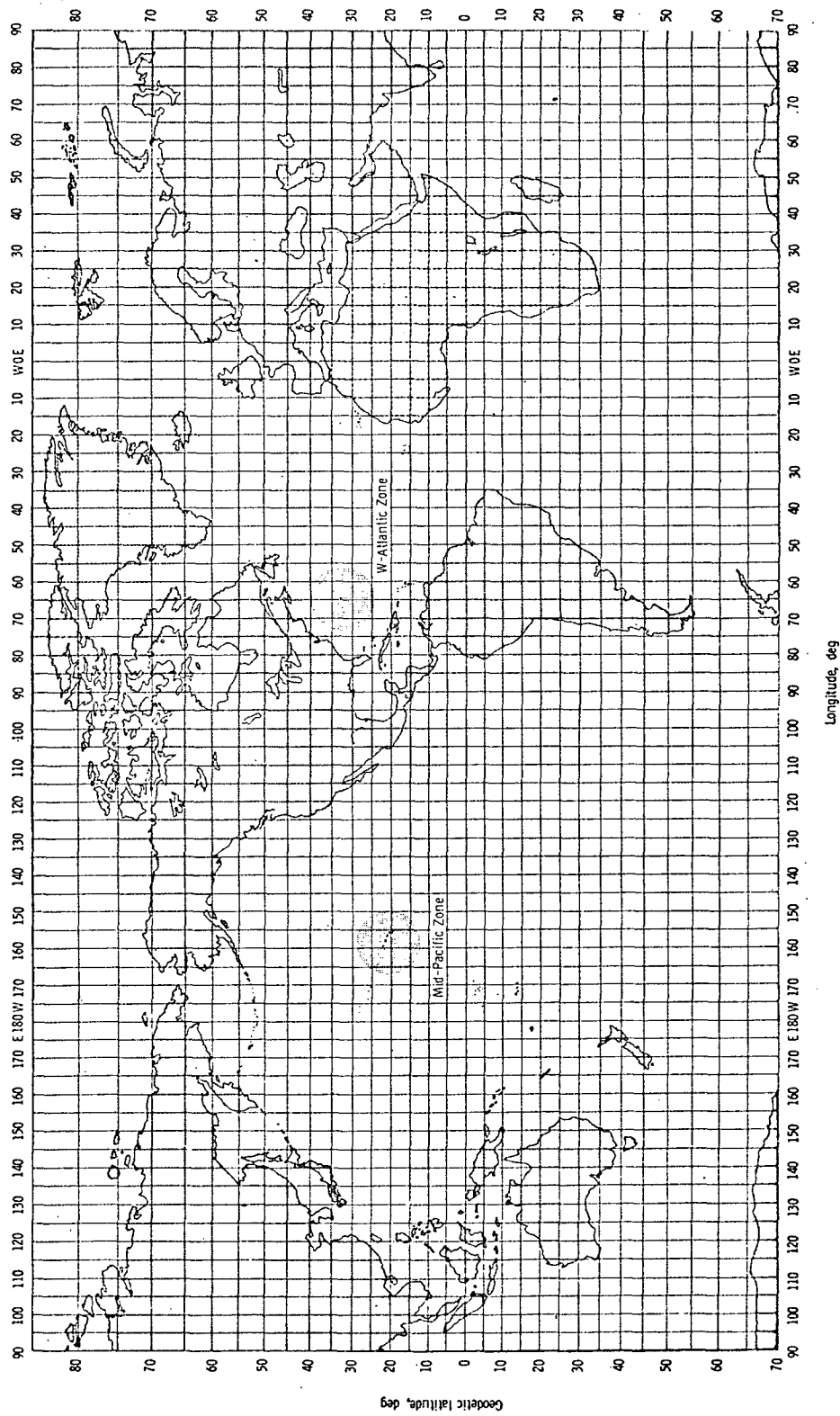


Figure 9. - Orbital mission recovery zones (two-zone port-centered support concept).

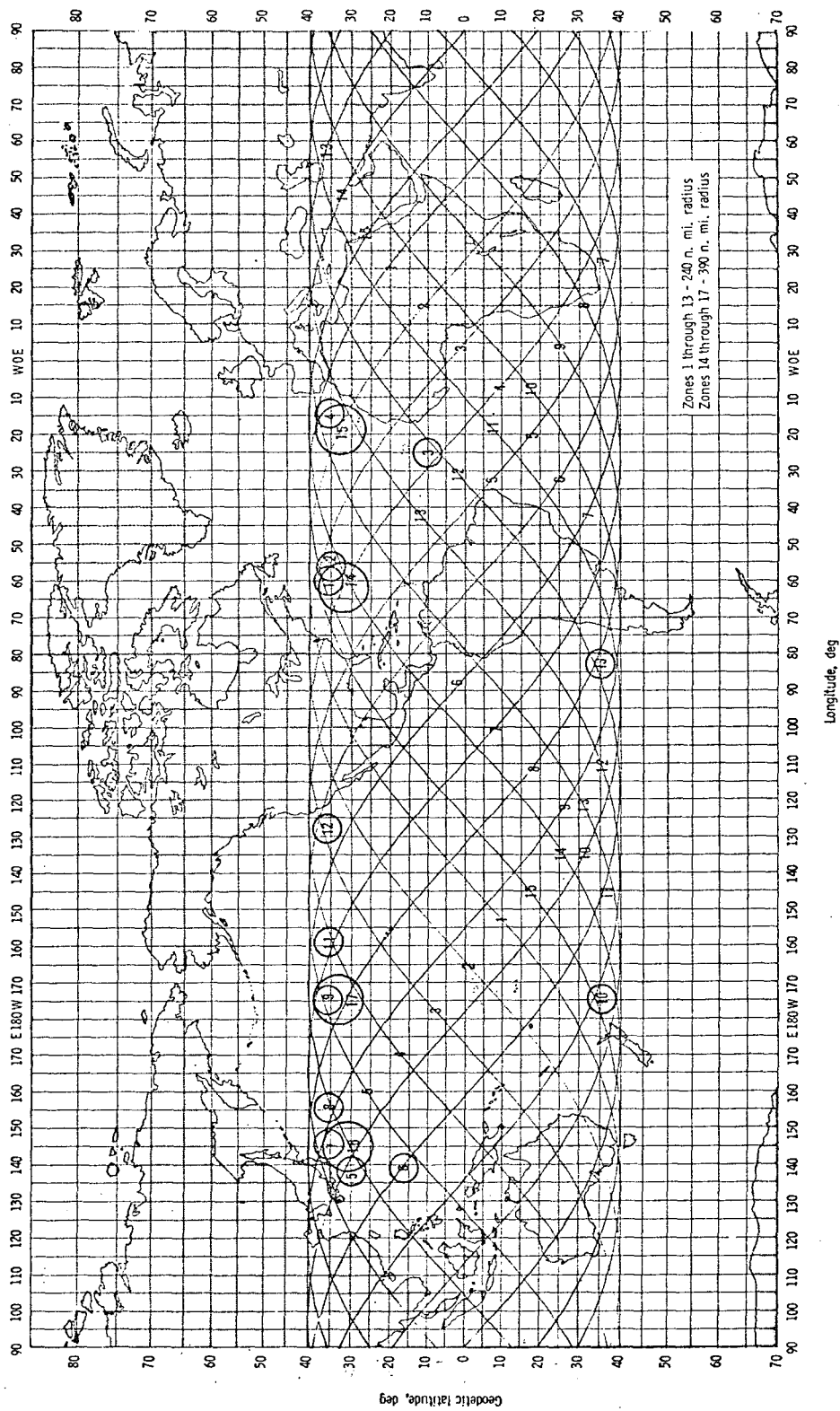


Figure 10. - Recovery zones considered for 40° inclination orbit circularized at 140 n. mi. altitude.

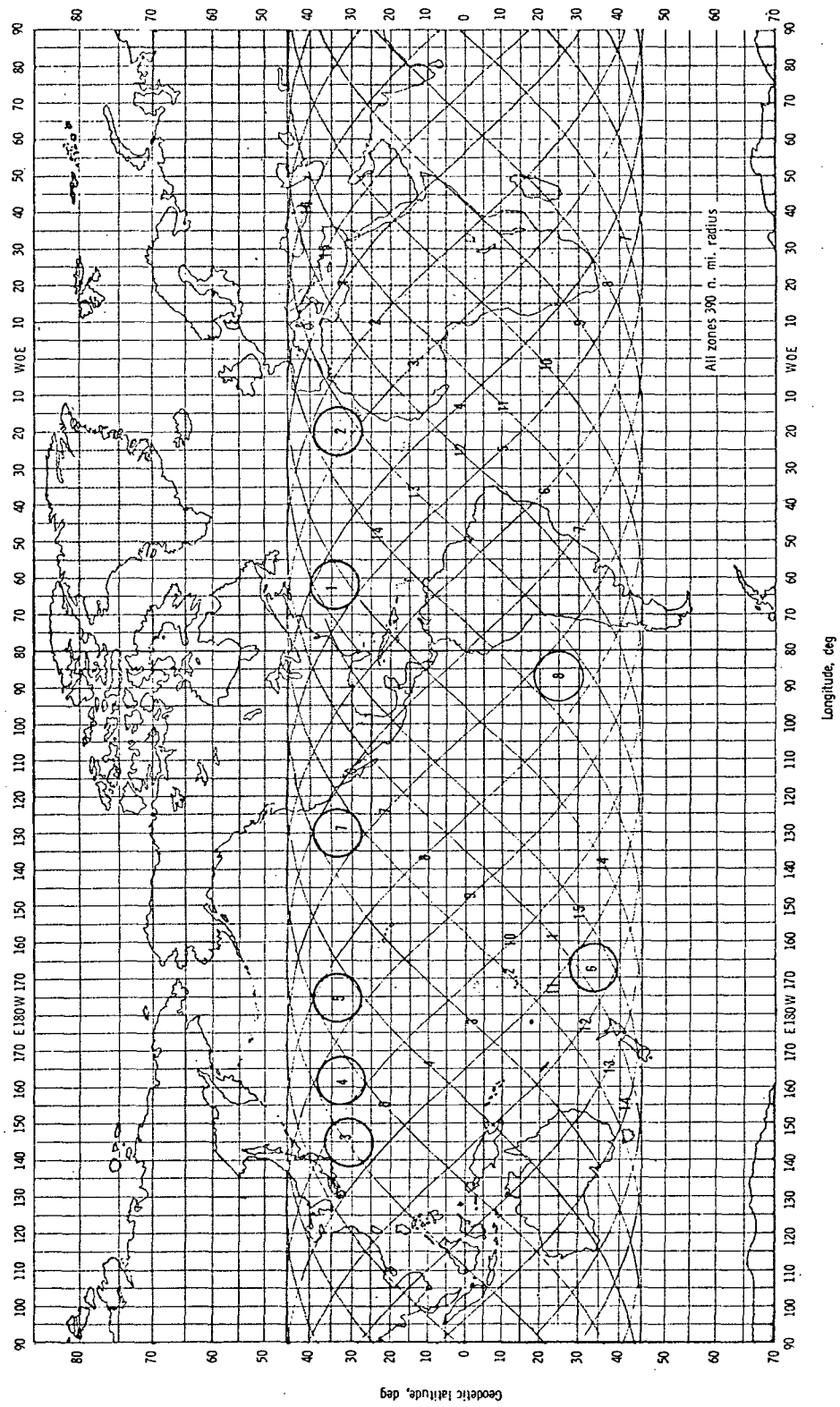


Figure 11. - Recovery zones considered for a 45° inclination orbit circularized at 140 n. mi. altitude.

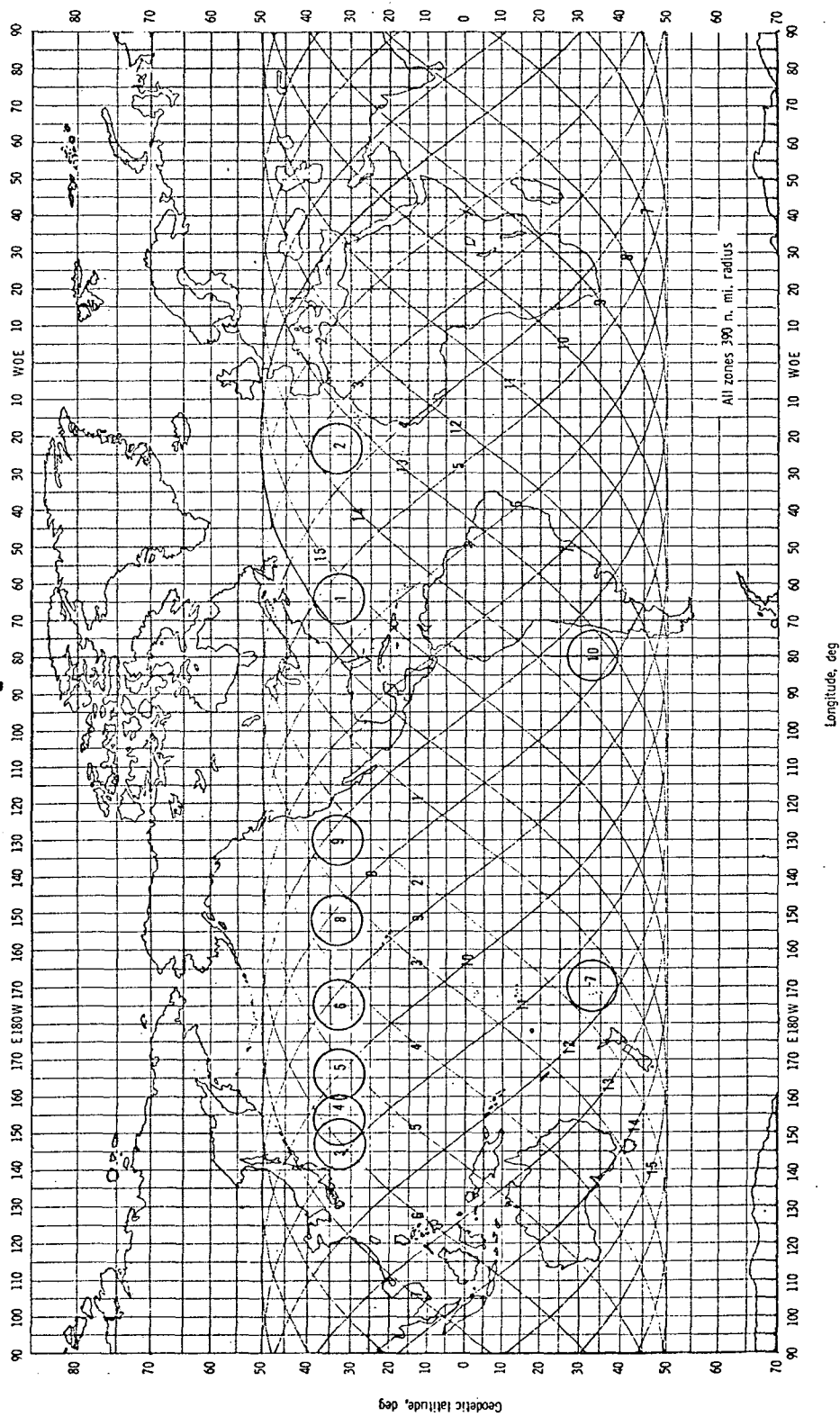


Figure 12. - Recovery zones considered for 90° inclination orbit circularized to 140 n. mi. altitude.

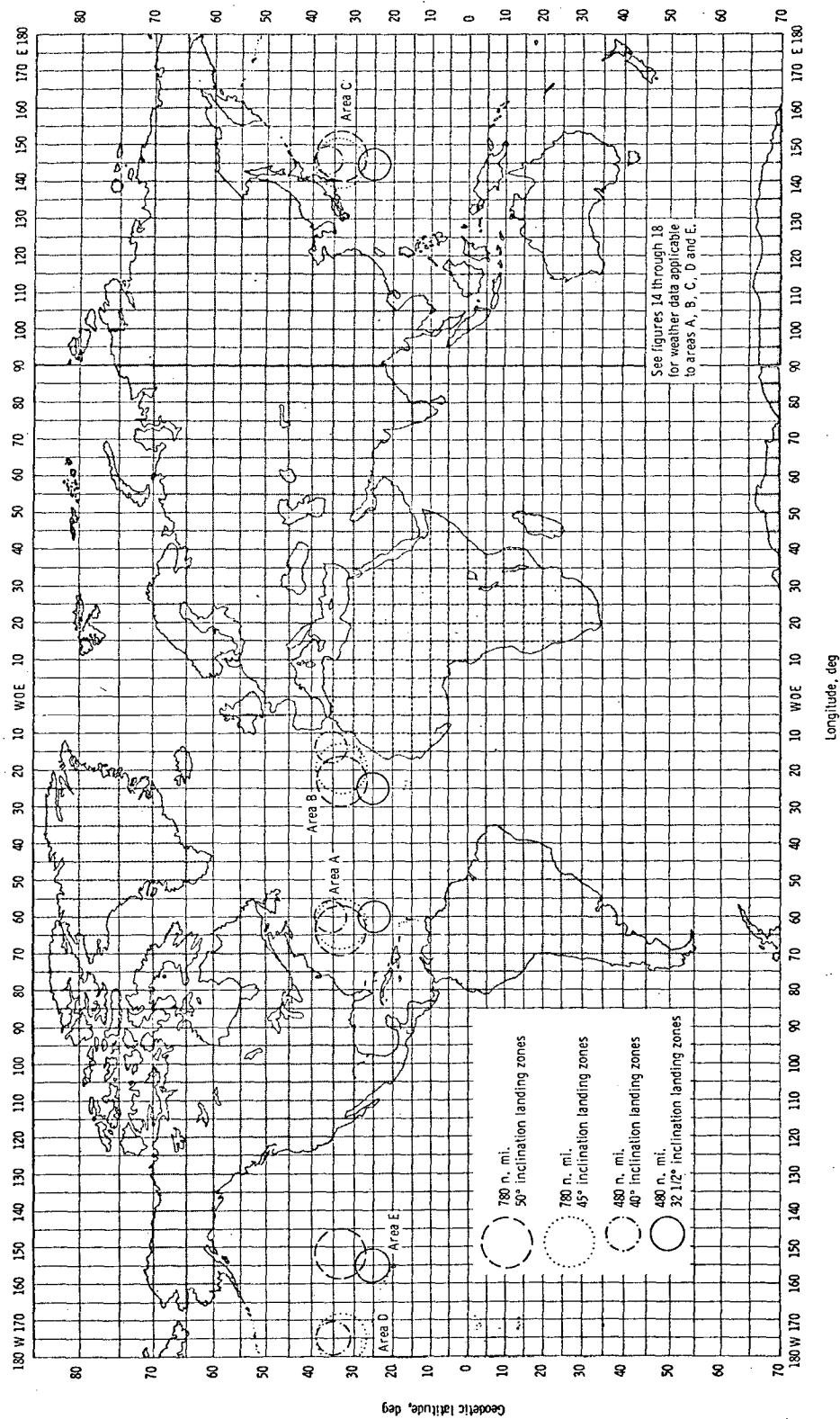


Figure 13. - Recommended recovery zones for high inclination missions having 140 n. mi. circular orbits.

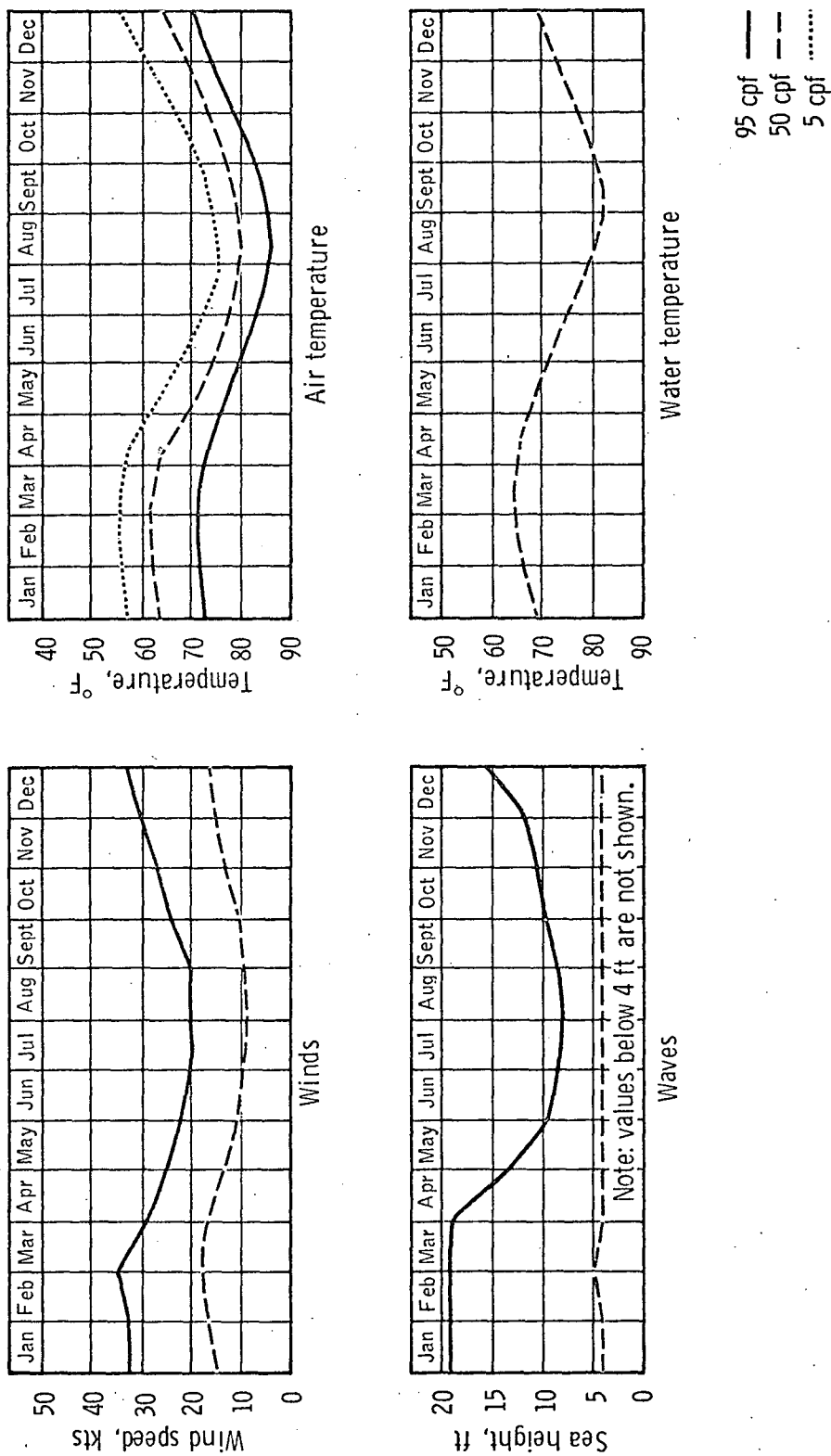


Figure 14.- Weather conditions in recovery area A for 40°, 45°, and 50° inclination missions.

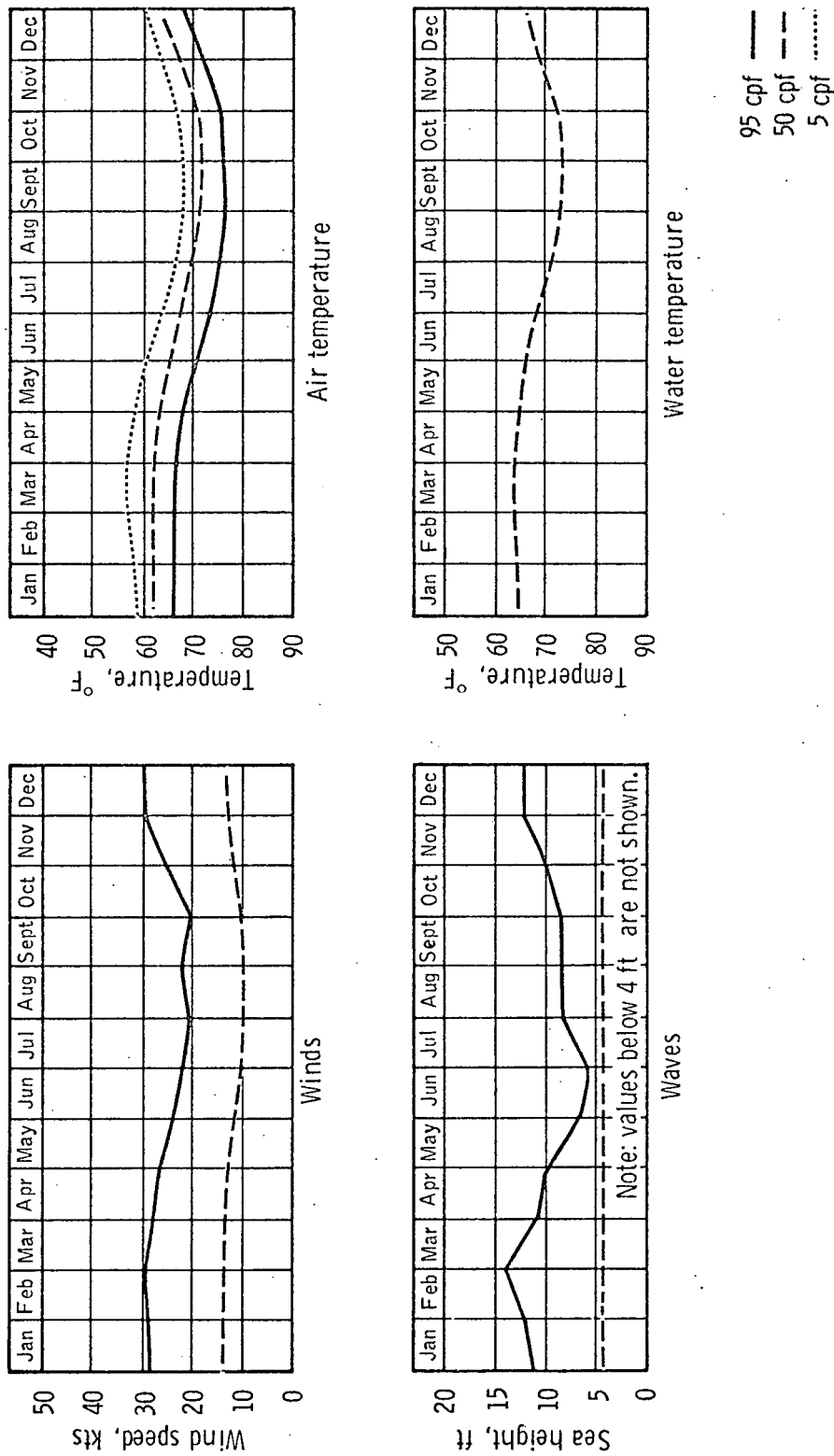


Figure 15.- Weather conditions in recovery area B for 40°, 45°, and 50° inclination missions.

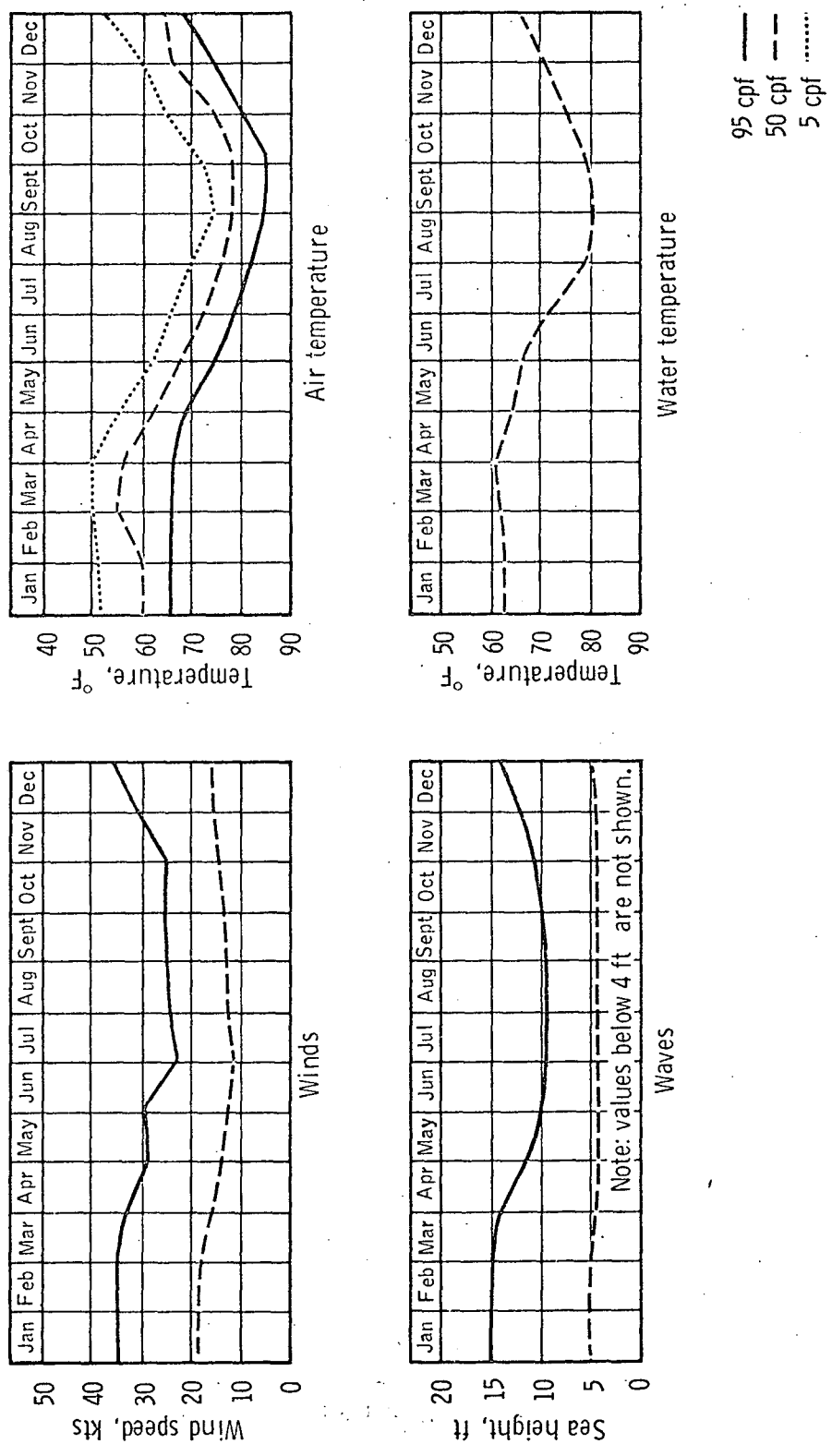


Figure 16.- Weather conditions in recovery area C for 40°, 45°, and 50° inclination missions.

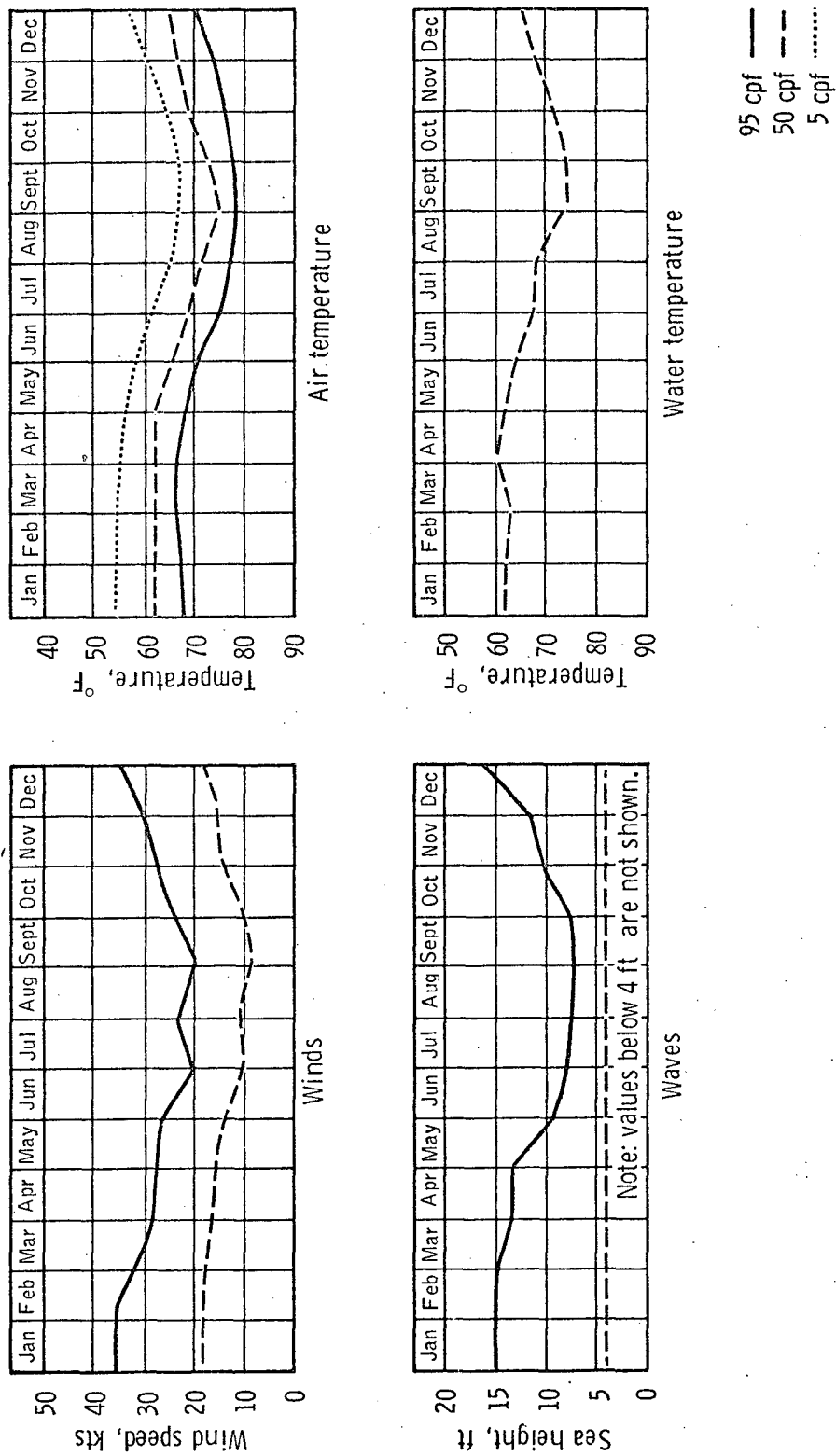
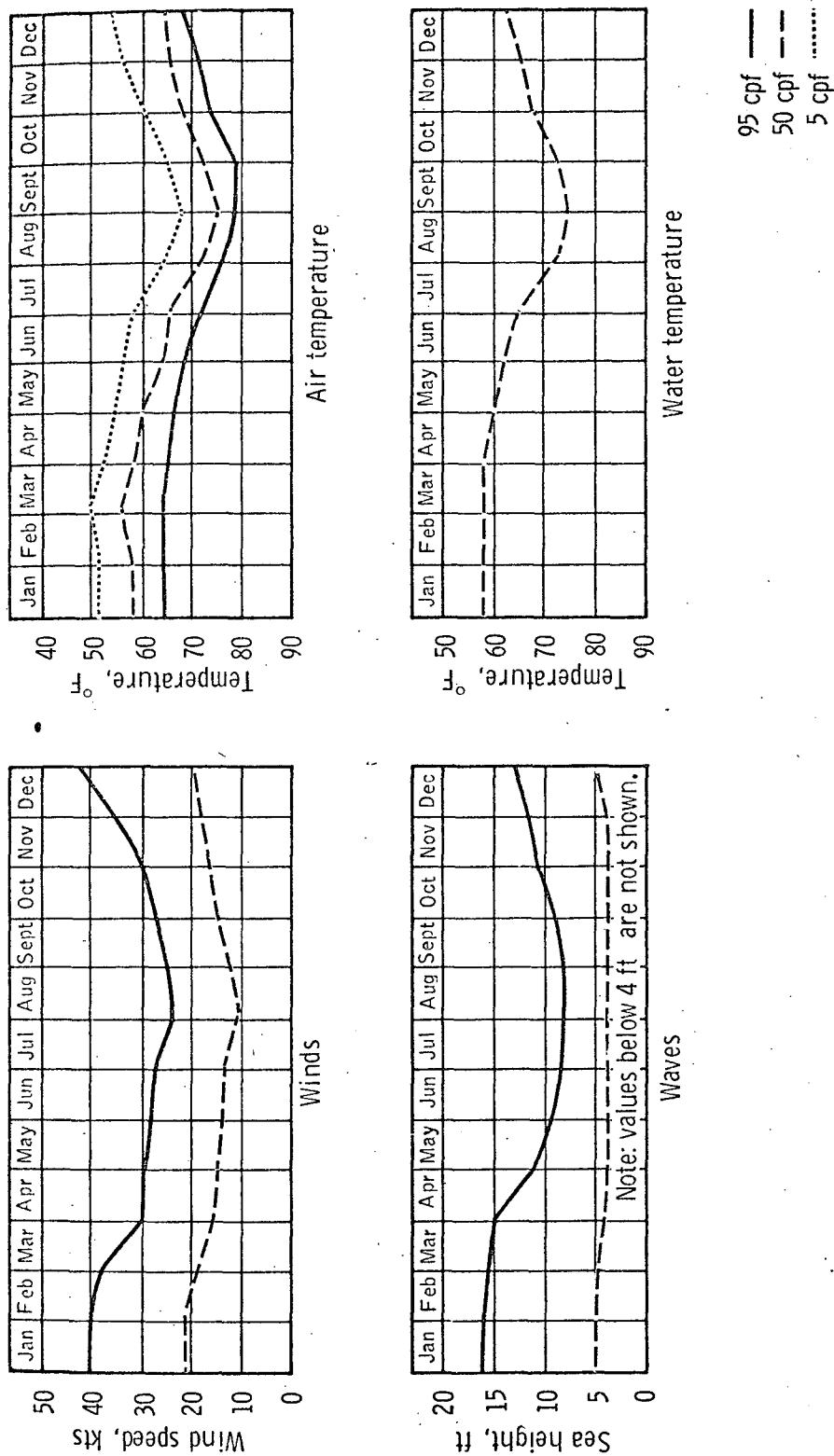


Figure 17.- Weather conditions in recovery area D for 40°, 45°, and 50° inclination missions.



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Figure 18.- Weather conditions in recovery area E for 40°, 45°, and 50° inclination missions.